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A STUDY OF THE TOLERANCE OF ROK AIR FORCE PERSONNEL TO GZ CENTR--ETC(U)
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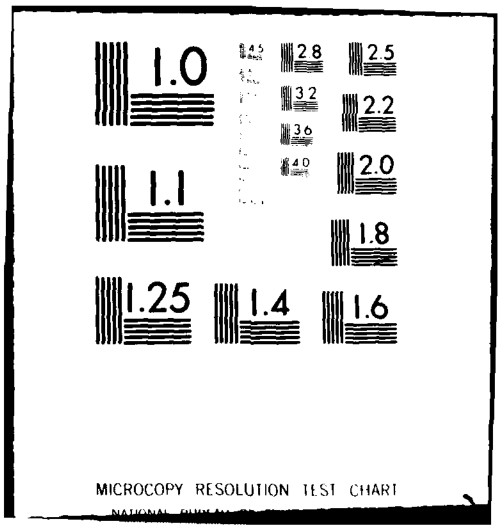
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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

A STUDY OF THE TOLERANCE OF ROK AIR FORCE PERSONNEL TO +Gz CENTRIFUGATION

by

Byung Kook Lee, Jung Min Hwang, et al.

FOREIGN TECHNOLOGY DIVISION

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A STUDY OF THE TOLERANCE OF ROK AIR FORCE PERSONNEL TO +Gz CENTRIFUGATION

Maj. Byung Kook Lee, M.D., Capt. Jung Min Hwang, M.D., Capt. Jong Sang Chois, M.D., Capt. Sang Goo Shin, M.D., Joung K. Park, M.D.

I. INTRODUCTION

After the success of the first experiments of the Wright brothers the development of of aircraft proceeded quickly, and from the days of propellar aircraft, the era of jets and supersonic flight soon followed; given these types of flight conditions, there is presently a clear need for biological research into the medical aspects of flight.

Given the capabilities of modern fighter aircraft for maneuverability and high speeds, the importance of studies on centrifugal forces, pressure changes and oxygen consumption has become increasingly apparent.[1].

During situations of positive centrifugation during maneuvers in fighter aircraft involving changes in direction, some problems relating to blood in the cardiovascular system have been noted including cerebral blood pressures of 0mm Hg in pilots of fighter planes pulling 5.5G.

Because of the relationship between spatial disorientation and various kinds of accidents, centrifugation and tolerance to it in the cardiovascular system including conditions under which it occurs and functioning of the system under such conditions have become an increasingly important problem.

According to the most recent American reports, fighters like the F-4E are capable of producing instantaneous accelerations of more than 8+Gz, and the F-15, in computer simulations has revealed the capability for producing acceleration levels higher than 10+Gz.[2] Because of these types of maneuver capabilities in fighters and their ability to produce such difficult G-force environments, research into methods of increasing the tolerance of pilots for such forces is continuing. Research into the G-forces exerted on pilots while executing M-1 and L-1 maneuvers as well as into the topic of PPB (Positive Pressure Breathing) is proceeding in a unified effort.[3] Much research is being carried out into the problems of the reasons for decreases in the tolerance of pilots for G-forces and the optimum conditions under which pilots can face the problem of these forces.[2]

Hand and hand with this, equipment has been developed and fielded (Human centrifuge) which, all at one time, allows a more scientific study of the phenomena of tolerance to positive G-forces and provides a means of training pilots to increase their tolerance to such conditions. Dr. P. Garsaux carried out the first experiments in aviation medicine in 1918, this research related to G-forces and involved the use of animals,[4] and the United States established facilities and carried out similar research.

At present, in our air force, equipment and facilities are being utilized for training and research in the area of tolerance to G-forces, and material of interest to aviation medicine has been discovered in these efforts. In pursuance of these efforts, the following experiments were carried out in order to compare the relative tolerances of pilots to pos-

itive G-forces as compared to the tolerance of ordinary officers and enlisted men to such forces as well as to ascertain what types of disruptive effects such positive centrifugation can have on the cardiovascular system.

II. OBJECTIVES AND METHODS OF EXPERIMENTATION

1. Objectives of Experimentation

176 pilots and 87 ordinary officers and enlisted personnel were utilized in these experiments, and their average physical characteristics are listed in Table 1.

Table 1. Physical characteristics of subjects

Group	No. of subject	Age (yr)	Height (cm)	Weight (kg)	Vital capacity (l)
Pilot	176	30.0±3.8	170.0±3.40	61.8±5.6	4.39±0.42
Non-pilot	89	22.3±1.5	169.7±3.85	60.1±6.2	4.13±0.53

Table 1

The ranks among the pilots used in these experiments ranged from 2LT to Colonel, and, because all ranks were represented in the sample of ordinary officers and enlisted personnel, the age of the pilots was greater the the average age of the ordinary group; however, there were no significant differences in height and weight between the two groups, and the pilots had better breathing capacity ($P<0.05$).

2. Methods of Experimentation

These experiments were carries out at the Aeromedical Research Center using the positive centrifugal forces generated by the G-force tolerance training equipment (Human Centrifuge; 2,000-c type: Emro Engineering Co.) which is installed there.

During these experiments, standard flight methods were employed with the G-force tolerence training equipment dependent on completion of a course in aerobiology where the pilots were concerned. (Fig 1) After a check of the equipment and the passengers in the gondola, the centrifugal force was slowly increased from 1.56G(Biostart) and then quickly raised to 6+Gz where it was held for 30 seconds, then, it was brought back down to 3+Gz during the course of 15 seconds; the force continued to be lowered 1+Gz every 15 seconds; the experiment was stopped at the first appearance of Black Out phenomenon (Fig 2). In the second type of centrifuge run, in which the G-force was increased 1+Gz every 15 seconds, physiolo-

gical compensation appeared between 0 and 11 seconds of the 15 second intervals. The experimental subjects were checked for effects on their cardiovascular systems using the Physiograph(Narco Bio-System Inc: Physiograph(R)Six).

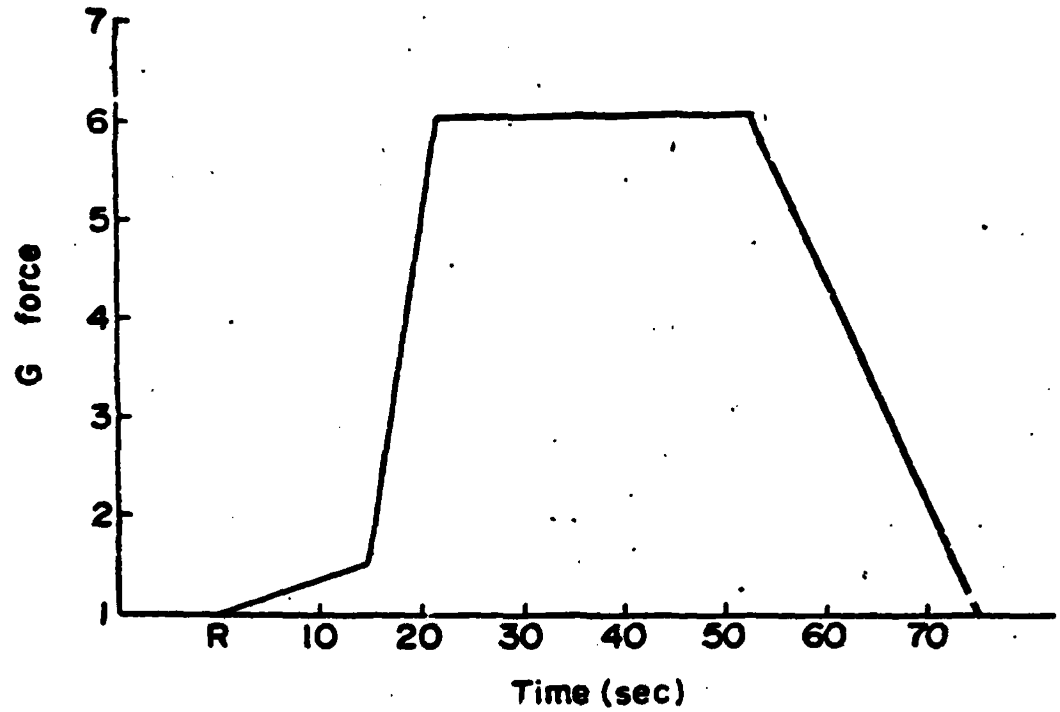

Fig 1. Standard +Gz acceleration profile

III. RESULTS

It can be seen from looking at Table 2 that, under standard flight conditions pulling 6+Gz for 30 seconds and considering the occurrence of tolerance and Black out phenomena, 159 of the 176 pilots or 90% exhibited tolerance; however, only 40 of the 89 ordinary personnel without flight experience or 45% exhibited tolerance. Considering the rate of tolerance failure while pulling 6+Gz for 30 seconds as broken down by rank (Table 3), except for the rank of captain which exhibited a tolerance rate of 84%, all the other rank groups had a success rate of 90% or higher.

Figure 3 displays a comparison of changes in heart rate as the result of flight under normal conditions.

Table 2. Comparison of tolerated & failed subjects at 6 +Gz for 30 sec between pilot & non-pilot group

Type of subject	No. of subject	Tolerated No.	Tolerated %	Failed No.	Failed %
Pilot	176	159	90	17	10
Non-pilot	89	40	45	49	55

Table 8. Comparison of tolerated & failed pilots at 6 +Gz for 30 sec by their classes.

Class	No. of subject	Tolerated No.	Tolerated %	Failed No.	Failed %
Second Lieutenant	9	9	100	—	—
First Lieutenant	50	42	84	8	16
Captain	36	33	92	3	8
Major	46	42	91	4	9
Lieutenant Colonel	31	29	94	2	6
Colonel	4	4	100	—	—
Total	176	159	90	17	10

Comparing the changes in heart rate of the pilots and the ordinary personnel in the groups that were tested for tolerance while pulling 6+Gz for 30 seconds, under the influence of positive centrifugal forces there was a straight-line increase in heart rate for the first 10 seconds at 6+Gz after which the values stabilized in the pilots; however, the ordinary officers and enlisted personnel exhibited an increase in heart rate over and above that of the pilots and which was conspicuously present after the first 5 seconds of flight; this difference of over 20 beats/min persisted until the end of the flight.

While pulling 6+Gz for 30 seconds, in the group that failed, the pilots failed after an average of 12.9 seconds while the ordinary officers and enlisted personnel failed after

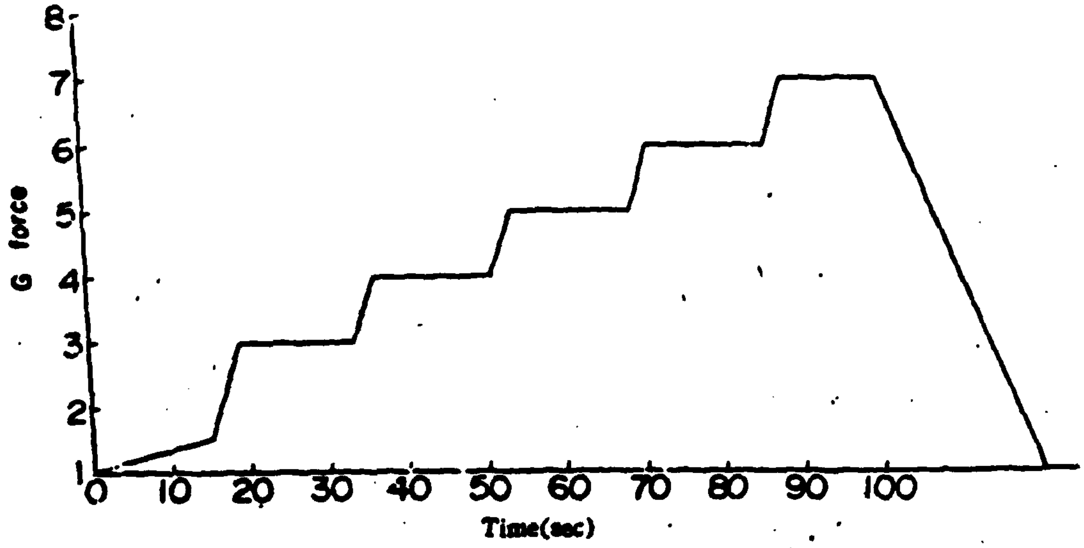

Fig 2. Modified +Gz acceleration profile

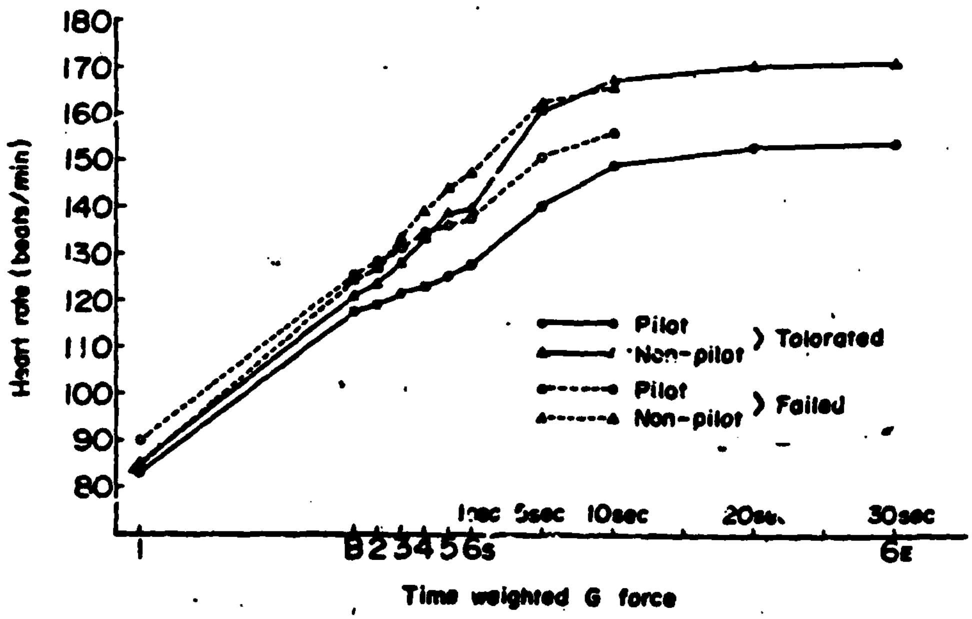

Fig 3. Comparison of the changes in heart rates between pilot and non-pilot group on +Gz acceleration.

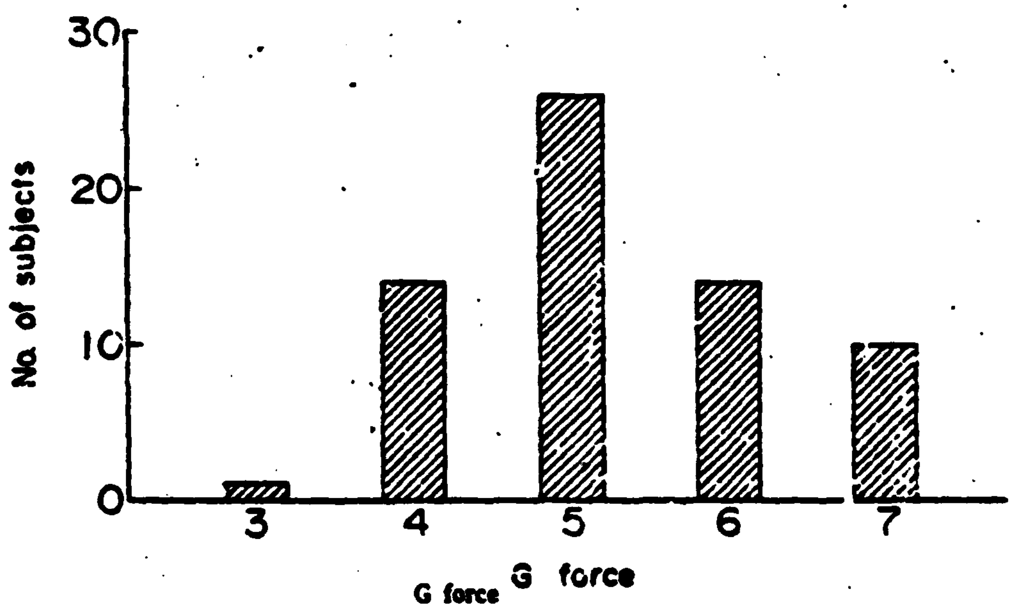

Fig 4. The distribution of +Gz tolerance of non-pilot group.

an average of 7.2 seconds; after the flights were interrupted because of these failures, the pilots exhibited comparitively higher heart rates and changes in heart rate than did the group of pilots that exhibited tolerance and, statistically speaking, there was no (one word missing on my copy) difference ($P > 0.05$); among the ordinary officers and enlisted personnel, there was no difference as compared to the non-pilot group that exhibited tolerance.

Fig 4 shows the distribution of tolerance achieved against positive centrifugal forces in stages during the flight; these stages of tolerance were achieved in 56 (sic) non-pilot personnel beginning with a 3+Gz force for 15 seconds followed by 1+Gz increments of increase until Black out occurred; this data was sought in order to ascertain what levels of tolerance existed to positive centrifugal forces when exerted against Korean personnel.

Arranging the non-pilot group according to how many positive G_z they could safely tolerate for 15 seconds, the results worked out like this: 3+Gz, 1; 4+Gz, 14; 5+Gz, 26; 6+Gz, 14; and 7+Gz, 10.

The overall tolerance of +Gz within this non-pilot group is displayed in Table 4 and reveals an average tolerance of 5.3+Gz with a standard deviation of ± 1.02 and a range of 3-7+Gz.

Table 4. Positive Gz tolerance of non-pilot group.

Number of subject	65
Mean	5.3
S.D.	±1.02
Range	3~7

Fig 5 shows the fluctuations in heart rate among the group that did show effective tolerance of +Gz, and these fluctuations are shown as a function of increases in the +Gz, employing standard flight methods, beginning from 3+Gz and increasing in stages each lasting 15 seconds.

Under these conditions, the heart rates in the subject group increased when subjected to a continuous increase in +Gz, and the results were as follows: at 1.56G (Biostart) there was an increase of from 105-116 beats/min; at 3+Gz there was an increase of from 114-124

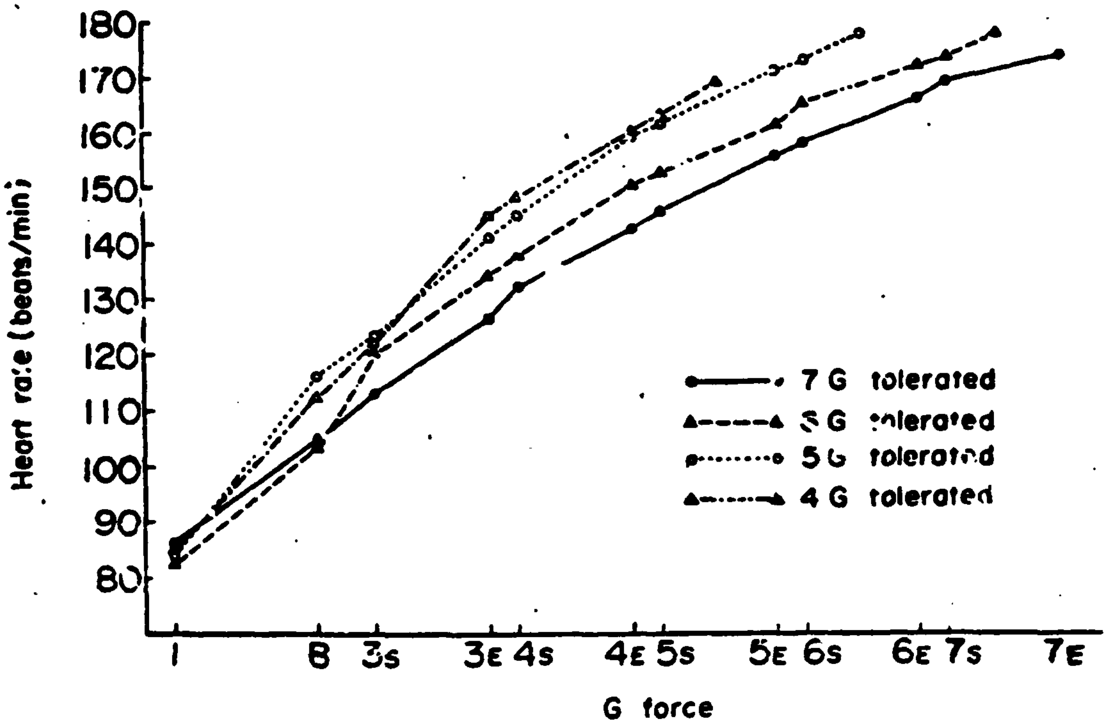

Fig 6. Changes in heart rate of non-pilot group according to the intencity of +Gz

beats/min at the beginning of the flight period and 126–145 beats/min at the end of the flight period; at 4+Gz the beginning and end measurements were 133–147 beats/min and 142–159 beats/min; at 5+Gz the measurements were 146–162 beats/min and 156–171 beats/min; at 6+Gz measurements of 158–173 beats/min and 166–172 beats/min were obtained.

The group that tolerated 7+Gz showed fluctuations in heart rate as a result of positive G-forces, and these fluctuations were consistently lower in actual number of beats/min relative to fluctuations in groups that could only tolerate lower +Gz

IV. EXAMINATION OF DATA

Acceleration is the rate of change of speed or direction over time. The types of acceleration produced during flight can be divided into linear acceleration and angular acceleration.

Linear acceleration occurs when a body moving in a staight line changes speed, and

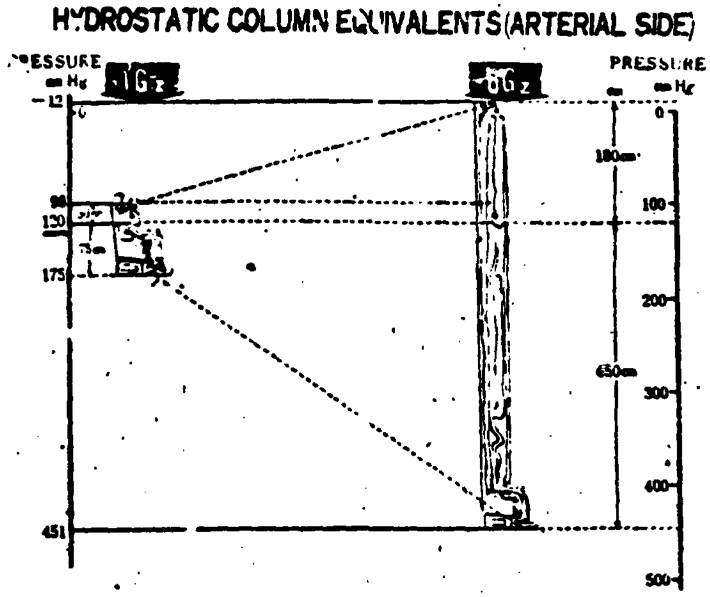

Figure 6. Hydrostatic pressure and systolic arterial pressure of a man seated in the upright position at + 1 G_z and + 6 G_z. (From Burton, Leverett, and Michaelson, 1974)

the type of linear acceleration called radial acceleration occurs when an object moving at a fixed speed changes direction. On the other hand, angular acceleration occurs when there are simultaneous changes in velocity and direction of an object[5].

The influence of acceleration on a human body varies with the strength of the energy applied, the time of application, the scope of application and the direction of application; if the area against which an acceleration is applied is small, the resulting injuries will be small, however, forces applied to the region of the head can produce grave injuries because of the differences between the head and the rest of the body.[6] In fact, acceleration is not the only factor determining the effects felt by the human body in such situations; the direction of application of the force of gravity as an increase in velocity is also an important factor in determining the tolerance of a given person. That is to say that accelerations, according to their direction of application, can be divided into positive, negative and lateral or horizontal types.[3] During aircraft flight the application of the energy of positive G-forces (+Gz) in a directional manner to the head area is a phenomenon which occurs often and is very important. The application of negative G-forces (-Gz) in an opposite direction to the area of the head in amounts greater than -3Gz creates a dangerous situation in which blood is drawn out of the head and the phenomenon of Red out

occurs. Horizontal accelerations applied forward and backward or left and right can be tolerated relatively well by the human body, and instantaneous accelerations of up to 15G can be withstood[7].

The forces of positive acceleration influencing the human body can be roughly classified this way: first, the influence of gravity on the body itself; second, influences on the respiratory system; and, most important, influences on the circulatory system. That is to say, as shown in Fig 6, seated in an upright position at 1+Gz, then the arterial blood pressure is 120mmHg, at a level 30cm above the heart, the arterial blood pressure in the brain was 22mmHg lower at 98mmHg; moreover, at a level 75cm below the heart, the pressure in the area of the feet was 175mmHg. If a force of 6+Gz is applied, the blood pressure cannot force blood up those 30cm to the brain in order to keep it supplied, so the subject lapses into a state of unconciousness. If the arterial pressure in the brain falls because of the effects of positive G-forces to a level 20mmHg below its former level, then there will be an inadequate blood supply to the retinas of the eyes and peripheral light loss occurs along with the so-called Grey out phenomenon; moreover, if the process continues, central vision will be affected, and Black out phenomenon will occur. The critical points controling the two phenomenon mentioned above have applications in many areas.[2]

However, the types of cardiovascular problems mentioned above occur at various levels of acceleration. For various complicated reasons, the ability to withstand acceleration, that is, tolerance exists at many different levels in different people. It is known that the ability to increase tolerance to acceleration through training can play an important role,[8] and, in our experiments, the fact that the pilot group, who had more experience with acceleration, displayed greater tolerance to acceleration than did the non-pilot group when the groups were both exposed to +6Gz for 30 seconds supports this point of view.

As far as increase in heart rate goes as a response to acceleration, in a kind of opposite or symmetrical reaction, the effect of acceleration is to reduce the blood pressure and the amount of blood being circulated; this causes the stretch receptors of the carotid sinus of the Aorta to initiate a contraction phenomenon in the blood vessels, and because of this the heart rate is increased[2]. As far as our experiments go, the experience we had with the pilot group in which heart beat levels of 150 beats/min occured representing an increase of approximately 11.3 beats/min for each increase of 1+G turns out to be somewhat lower than the experience of Lambert and others in similar experiments[9]; moreover, the corresponding 14.7 beats/G rate of increase in the non-pilot group was rather higher. These results reflect the fact that greater flight experience of the pilots and their correspondingly increased tolerance of acceleration lessened the burden on their circulatory systems. Among the pilots, those at the rank of captain who had a lot of flight experience showed higher rates of tolerance, and this fact supports the idea that

Table 5. Comparative data of +Gz of ROKAF with other countries.

	Type of subject	No. of subject	Acceleration rate (G/sec)	+Gz tolerance	
				Mean±S.D.	Range
Korea	ROKAF Pilot	176	0.7	6.0	3~7
	ROKAF Non-pilot	65	0.4	5.3±1.02	
U.S.A.	Naval aviation cadet	1,000	1.0	5.4±0.9	3.0~8.4
Japan	Non-pilot	21	0.1	5.7±0.3	4.1~6.0

progressive exposure to acceleration increases tolerance of it.

On the other hand, concerning the tolerance of the non-pilot group which had no flight experience to the phased positive accelerations to which they were exposed, this group achieved an average tolerance of 5.3+Gz± 1.02 in a range of from 3 to 7 Gz; how this compares to similar data developed on American and Japanese subjects can be seen in Table 5; in terms of Onset ratio, although there are differences, similar values were achieved for all groups, and, in terms of tolerance to positive acceleration, there seems to be no difference between oriental and occidental personnel; when one considers increases in heart rate as a function of increase in +Gz, however, the group which had a high tolerance for G-forces had low changes in heart rate and less influence on their circulatory systems; this squares with the results of our tests at 6+Gz for 30 seconds.

V. CONCLUSIONS

In order to understand the influences which affect the circulatory system of the human body and its tolerance to the positive accelerations produced during the flight of fighter aircraft, we conducted acceleration flight experiments using acceleration tolerance training equipment (Human Centrifuge: 2,000-C type; Emro Engineering Co.) and contrasting 176 ROK Air Force pilots with 89 non-pilot officer and enlisted personnel.

The experiments were conducted in this manner; after the subjects got on board the gondola and physiological monitoring equipment was connected to them, we started the machine and, after gradually achieving Biostart at 1.56+Gz, we rapidly increased the acceleration to 6+Gz and held it there for 30 seconds; this was the first method employed; the second was to increase the acceleration in steps beginning at 3+Gz for 15 seconds and increasing the acceleration by 1+G after each 15 second exposure until Black out phenomenon occured.

In order to understand the effects of these accelerations on the circulatory systems of the subjects, we used a Physiograph to measure changes in heart rate and got the results listed below.

1. During the exposure to 6+Gz for 30 seconds, 90% of the pilots tolerated the acceleration, but only 45% of the non-pilot personnel tolerated the same exposure; the rest of each group experienced Black out phenomenon during the test and were terminated before the test period was completed.

2. When the degree of tolerance to G-forces among the pilot personnel was compared to the ranks of the pilots involved, it was found that those pilots who held the rank of captain had the highest tolerance levels.

3. During the course of an exposure to 6+Gz for 30 seconds it was found that the pilot group had relatively less change in their heart rates than did the non-pilot personnel; moreover, the circulatory systems of the pilots were affected less.

4. Over all, the non-pilot group achieved an average tolerance to positive G-forces of 5.3 ± 1.02+Gz with a range of tolerances from 3 to 7+Gz.

5. Over all, when the tolerances achieved by various individuals to positive accelerations under the conditions of these tests were compared to changes in heart rate as accelerations were increased, it turned out that groups with relatively higher tolerances to positive accelerations had lower changes in heart rate.

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- Summary -

The Study on the Tolerance of ROK Airforce Meu to +Gz Centrifugation

Aeromedical Research Center

Maj., Byung Kook Lee, M.D.
Capt., Jung Min Hwang, M.D.
Capt., Jong Sang Chois, M.D.
Capt., Sang Goo Shin, M.D.
Joung Kook Park, M.D.

In order to determine the human tolerance to positive acceleration and evaluate the effect of +Gz on cardiovascular system, 176 pilots and 89 non-pilots were selected to take centrifuge running on Human Centrituge: 2,000-type C; Emro Engineering Co.

All subjects were exposed to the rapid onset profile of 6 +Gz. with 30 second plateu which was started slowly to 1.56 +Gz(Biostart) and increased rapidly to 6+Gz. The second profile of centrifuge running with non-pilot group was stepwise running from 3 +Gz to the tolerable high +Gz. The increase of 1 +Gz was followed by every success of 15 second running of +Gz. The centrifuge running was stopped at the sign of black out phenomena of subject.

The changes of heart rates was checked in order to evaluate the cardiovascular effect of +Gz with physiograph.

The results obtained were as follows.

1. The pilot group were tolerated 90% in rapid onset profile of 6 +Gz with 30 second plateu and non-pilot group were 45% only.

Summary (cont.)

2. The high ranks of pilot group had higher tolerance rate than lower ranks of pilot group.

3. The changes of heart rates of pilot group at 6 +Gz with 30 second plateu was relatively smaller than non-pilot in the case of tolerated group of centrifuge runs. It means that the pilot group had relative little burden of +Gz on cardiovascular system.

4. The +Gz tolerance of non-pilot group achived from 2nd centrifuge run was 5.3 +Gz ± 1.02 (Range 3 − 7 +Gz)

5. The changes of heart rates of highest +Gz tolerance group at the 2nd centrifuge run according to the increase of +Gz was relatively smaller than lower +Gz group.